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Fluid and Electrolytes: Parenteral Fluid Therapy

Kenneth B. Roberts, MD*

Objectives After completing this article, readers should be able to:

1. Relate maintenance fluid and electrolyte needs to metabolic rate rather than to body weight.
2. Recognize the differences in mild, moderate, and severe deficits among infants compared with children or adults when expressed as percentage of body weight.
3. Describe the indication for a “bolus” and specify the amount and composition.
4. Specify a rehydration plan without the use of a calculator for an infant who has moderate dehydration.
5. List the measures most valuable for monitoring the state of hydration.

Introduction

Parenteral fluid therapy is a basic component of the care of hospitalized infants and children. Clinicians who care for inpatients must be able to assess the need for parenteral fluid therapy and to specify the composition of fluid and rate of administration. Fluid and electrolyte problems can be challenging but generally can be “tamed” by an organized approach, application of a few principles of physiology, and careful monitoring of the patient. It can be useful to consider separately the amount of fluid needed and the electrolyte composition for maintenance needs, deficit, and ongoing losses (Table 1). Because maintenance is not as directly related to weight as deficit or as directly measurable as ongoing losses, it tends to cause the most confusion. It will, therefore, be discussed first and in more detail than deficit or ongoing losses.

Maintenance: Fluid

The key to understanding maintenance fluid and electrolyte needs is recognizing that they stem from basal metabolism (Fig 1). Metabolism creates two by-products, heat and solute, that need to be eliminated to maintain homeostasis. Heat is dissipated largely by the insensible evaporation of water from the skin surface. (Active “sensible” skin loss—sweating—is added only when there is an additional heat burden and is not considered part of maintenance.) Elimination of warmed water vapor from the upper respiratory tract during exhalation also contributes to insensible fluid loss. Soluble waste by-products of metabolism are excreted in the urine.

Metabolic rate is not related directly to weight and is expressed in units of energy (kcal or joules). When compared with body weight, basal metabolic rate is high in the newborn period and much lower in adulthood, and the transition is not linear (Fig 2). Because metabolic rate per unit of body weight declines with increasing age, children generate less heat and solute from basal metabolism than do infants and, therefore, need less fluid and electrolytes per unit of body weight. Adolescents and adults generate less heat and solute from basal metabolism than do children or infants and, therefore, need less fluid and electrolytes per unit of body weight. Although the amount of fluid and electrolytes declines per unit of body weight, it remains constant per kilocalories of basal metabolism.

Because it is difficult to remember basal metabolic rates for various ages and sizes during childhood, several methods have been proposed to relate maintenance needs to body weight, including the surface area method, the basal calorie method, and the Holliday-Segar system. All three systems “work” when used by knowledgeable individuals, but each

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Table 1. Approach to a Fluid and Electrolyte Problem

	Fluid (Amount of Water)	Electrolytes (Composition)
Maintenance	Determined by a "system": Holliday-Segar formula, surface area, or basal calorie method	D ₅ 0.2NS + 20 mEq/L K ⁺
Deficit	Determined by acute weight change or clinical estimate	Determined by tables (generally D ₅ 0.45NS + 20 mEq/L K ⁺)
Ongoing Losses	Determined by measuring	Determined by tables or measuring

also has its problems. The surface area method requires a table to determine surface area and ideally knowledge of the patient's height and weight, different proponents advocate different estimates of fluid to be administered per m², and the system does not address deviations from normal activity. The basal calorie method also requires a table, it involves the most calculations, and it is "drier" than the other methods. The Holliday-Segar system, as generally applied, does not address deviations from normal activity, but it is used most frequently because of the ease with which the formula can be remembered and applied (Table 2).

The Holliday-Segar formula estimates kilocalories that, for practical purposes, can be equated with milliliters of fluid. (For each 100 kcal expended, approximately 50 mL of fluid is required to provide for skin, respiratory tract, and basal stool losses, and 55 to 65 mL of fluid is required for the kidneys to excrete an ultrafiltrate of plasma at 300 mOsm/L—a specific gravity of 1.010—without having to concentrate the urine. The sum generally is rounded to 100 mL of fluid per 100 kcal expended, permitting kilocalories and milliliters to be used interchangeably.) The two functions of maintenance fluid (heat dissipation through insensible losses and solute excre-

tion in urine) each can be considered as representing 50% of maintenance needs. This simple principle is a great aid in the management of children who have anuric renal failure. Maintenance fluid needs decrease by 50% because the only fluids needing to be replaced are insensible losses.

Are maintenance fluid and electrolytes all that children at bed rest in the hospital need? All children have maintenance needs, but most hospitalized children have

more than maintenance needs. They may be febrile, needing fluid to dissipate additional heat; they may be in a catabolic state, producing additional solute to be excreted; or they may be sequestering fluid in a "third space" as a result of inflammation or low intravascular colloid pressure. In addition, nutrition includes and creates additional osmoles that need to be excreted, requiring additional fluid.

In the absence of disease, should intake and output be equal, or should urine output always equal half of what is taken in? Intake and the output that is measured (mainly urine) should not be equal because insensible losses contribute to losses but are not measured. The half-half rule applies when the child has only maintenance needs and the amount of fluid being provided matches those needs. Normal kidneys have the ability to modulate the amount of water excreted, but insensible losses come "off the top." Therefore, as demonstrated in Table 3, if more fluid is provided than is needed for maintenance, urine will be dilute and exceed 50% of the intake; if less fluid is provided than is needed for maintenance, urine will be concentrated and be less than 50% of intake.

Should maintenance fluids be administered evenly each hour? The convention of infusing maintenance fluids at a uniform hourly rate is convenient for the individual making the calculation and for the staff monitoring the infusion, but it is only a convention. Maintenance fluids certainly are not ingested at an even rate when consumed orally, and they do not need to be provided evenly when infused parenterally. Flexibility is encouraged when it is not convenient for fluids to be infusing or when the intravenous access

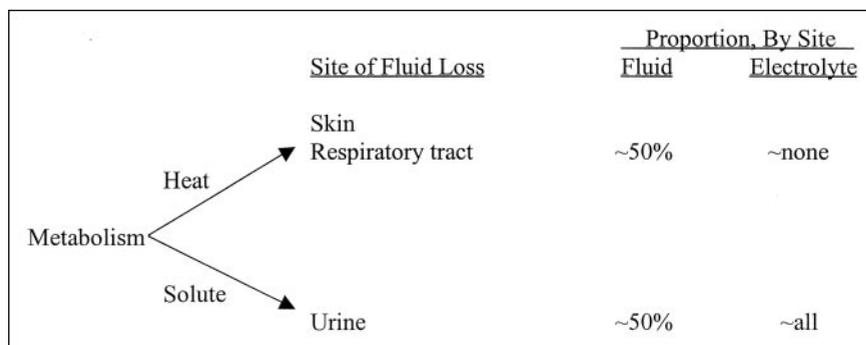


Figure 1. Maintenance fluid and electrolytes are required because of losses that stem from basal metabolism.

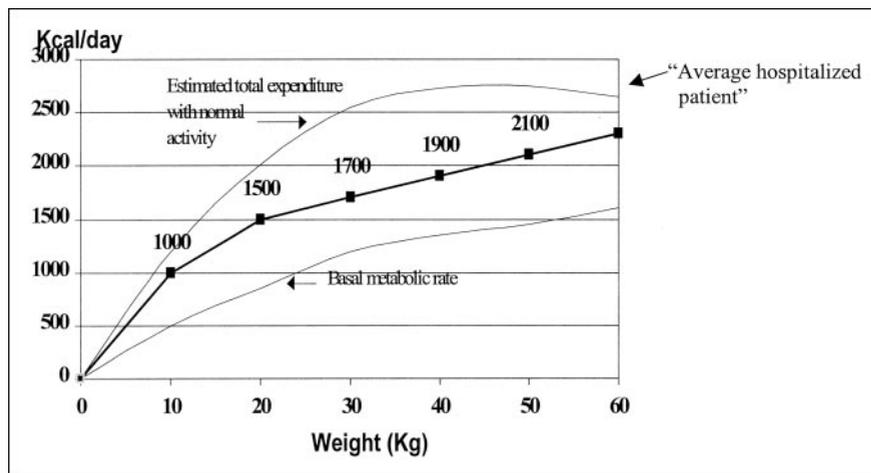


Figure 2. Basal metabolic rate, estimated total expenditure with normal activity, and caloric expenditure of the "average hospitalized patient."

needs to be used for a different purpose, such as the administration of a medication that needs to be infused slowly (eg, vancomycin). Acceptance of the convention to infuse maintenance fluids at an even rate can make rehydration calculations unnecessarily difficult.

Maintenance: Electrolytes

Fluid is lost from the skin largely by evaporation, and that lost from the respiratory tract consists of water vapor. Hence, insensible loss contains virtually no electrolytes. For clinical purposes, all electrolyte loss can be considered to be urinary. This further informs the treatment of patients who have anuric renal failure. Because their sodium and potassium are "recycled," no sodium or potassium administration is required. (If the patient is oliguric rather than totally anuric, the amount of sodium lost in the urine can be determined in the laboratory and replaced as an "ongoing loss.")

Table 2. Holliday-Segar Formula for Determining Calories (and Fluid Volume) for "Average Hospitalized Patient" at Maintenance

Weight (kg)	kcal/d or mL/d	kcal/h or mL/h
0 to 10 kg	100/kg per day	4/kg per hour
11 to 20 kg	1,000 + (50/kg per day)*	40 + (2/kg per hour)*
>20 kg	1,500 + (20/kg per day) [†]	60 + (1/kg per hour) [†]

*For each kg >10.
[†]For each kg >20.
 From Holliday MG, Segar WE. The maintenance need for water in parenteral fluid therapy. *Pediatrics*. 1957;19:823-832

Should the sodium concentration of maintenance fluids provided to adolescents and adults differ from that generally provided to infants and children? The sodium concentration need not differ. Both the amount of electrolyte and the amount of water for maintenance needs are based on metabolic rate, not on body weight. The ratio of electrolyte to water is fixed, so the composition of maintenance fluids should remain constant: D₅0.2NS + 20 mEq/L K⁺. Adolescents and adults frequently are provided D₅0.45NS, based on a presumed need for sodium of 3 mEq/kg, when the actual need is 3 mEq/100 kcal. The error of calculating sodium based on weight results in a linearly increasing amount with increasing weight, when fluid needs actually decrease with advancing weight (Fig 2).

This results in adults generally being provided more sodium than needed for maintenance support, as was recognized nearly 50 years ago. To illustrate the difference, a teenager or adult weighing 70 kg would receive 2,500 mL/d of fluid, based on the Holliday-Segar formula. At 3 mEq/100 kcal, the individual would receive 75 mEq/d of sodium (1.7 g), but at 3 mEq/kg, the individual would receive 210 mEq/d of sodium (nearly 5 g), which is much more than is required to meet maintenance needs.

Deficit: Fluid

A deficit is the amount of water (and electrolytes) lost before treatment is begun. For practical purposes, it is a one-time estimate, and additional abnormal losses are considered in the category of ongoing losses. Acute weight change is the most direct basis for determining the amount of deficit fluid; a loss of body weight greater than 1% per day almost always must be fluid. However, weight change can be misleading. For example, retention of fluid in a "third space" may lead to intravascular depletion without a corresponding drop in body weight. Clinical estimates of dehydration are useful when a preillness weight is not available or the differ-

Table 3. Relationship of Intake and Urine Output in a 10-kg Child Receiving Various Volumes of Fluid*

	At Maintenance	More Than Maintenance	Less Than Maintenance
Volume	1,000 mL	2,000 mL	750 mL
Insensible loss	500 mL	500 mL	500 mL
Fluid available for urine	500 mL	1,500 mL	250 mL

*Note that urine output is half of intake only if the maintenance amount is provided.

ence between the current weight and the preillness weight does not seem to reflect the child's clinical condition accurately (Table 4). Dry mucous membranes in association with normal hemodynamic measurements indicate mild dehydration; early hemodynamic signs of intravascular depletion (eg, tachycardia) define moderate dehydration; and signs of more profound hypovolemia (eg, hypotension, poor perfusion) are considered evidence of severe dehydration. Mild, moderate, and severe degrees of dehydration in infants correspond roughly to a loss of 5% (50 mL/kg), 10% (100 mL/kg), and 15% (150 mL/kg) of body weight, respectively. In teenagers and adults, however, the loss generally is only half as great. Some authors suggest an estimate of 3% (30 mL/kg), 5% (50 mL/kg), and 7% (70 mL/kg) for mild, moderate, and severe dehydration, respectively; others recommend 3% (30 mL/kg), 6% (60 mL/kg), and 9% (90 mL/kg). For children between the newborn period and adolescence, intermediate values should be applied.

Serum sodium concentration affects the clinical signs of dehydration. Hyponatremia causes an exaggeration of

hemodynamic instability; hypernatremia maintains circulatory sufficiency at the expense of intracellular depletion.

The rapidity with which the deficit is replaced depends on the degree of dehydration and on how long it has taken for dehydration to develop. (Hippocrates: "Those bodies which have been slowly emaciated should be slowly recruited; and those which have been

quickly emaciated should be quickly recruited.") Rapid "recruitment" not only restores intravascular volume and diminishes myocardial work, but it also promotes an improved sense of well-being that often literally "recruits" the child to be able to drink and ends the need for parenteral fluid. If signs of hypovolemia are present (eg, tachycardia, hypotension), a rapid infusion of fluid ("bolus") is indicated. The amount generally administered in a single bolus is 20 mL/kg for infants and children and 10 mL/kg for teenagers.

By convention, dehydration often is expressed as percent of body weight, and bolus replacement is considered in milliliters per kilogram of body weight. This mismatch of units is unfortunate. Recognizing that 20 mL/kg is equivalent to 2% of body weight permits the clinician to set expectations for the impact of a bolus of fluid. For example, an infant who is estimated to have lost 10% of body weight and is tachycardic can be expected to have a lower heart rate after a single 20 mL/kg bolus, but an infant who is estimated to have lost 15% of body weight

Table 4. Clinical Assessment of Dehydration in Infants and Adolescents

Infant		Adolescent		Severity of Dehydration	Clinical Data	Problems in Assessment
EWL	mL/kg	EWL	mL/kg			
5%	50	3%	30	Mild	<ul style="list-style-type: none"> • Dry mucous membranes • Oliguria 	<ul style="list-style-type: none"> • Oral mucosa may be dry in chronic mouth breathers • Frequency and amount of urination may be difficult to assess during diarrhea, especially in infant girls
10%	100	5% to 6%	50 to 60	Moderate	<ul style="list-style-type: none"> • Marked oliguria • Poor skin turgor • Sunken fontanelle • Tachycardia 	<ul style="list-style-type: none"> • See oliguria above • Affected by serum $[Na^+]$ • Infants only
15%	150	7% to 9%	70 to 90	Severe	<ul style="list-style-type: none"> • Hypotension • Poor perfusion 	<ul style="list-style-type: none"> • Affected by fever, $[Na^+]$, underlying disease • Both may be affected by $[Na^+]$, underlying disease

EWL = estimated weight loss
 $[Na^+] > 150$ mEq/L gives falsely low estimate of severity; $[Na^+] < 130$ mEq/L exaggerates clinical estimate of severity

will require more than one such bolus to regain a comparable degree of hemodynamic stability.

Deficit: Electrolytes

Normal saline or Ringer lactate is used when a bolus of fluid is administered because the sodium concentration is comparable to serum, so intravascular volume is bolstered without fluid shifts. The remainder of the deficit rarely requires such a high sodium concentration. In the usual situation, in which the deficit has been incurred because of excessive gastrointestinal losses or a short period of reduced intake or both, the total sodium loss is approximately 80 to 100 mEq/L. Particularly when a bolus of normal saline or Ringer lactate has been provided, the remaining deficit is approximated by half-normal saline (D₅0.45NS).

Only sodium needs are calculated. The amount and rate of potassium administered is governed by safety, and full replacement is not achieved acutely. Once urine output is assured, and, therefore, it is considered safe to administer potassium, 20 mEq/L is added to the replacement solutions. If hypokalemia is a concern, the concentration of potassium in replacement fluids can be increased, but the rate of infusion must be considered as well. The limiting factor is the amount of potassium infused per unit time, which should not exceed 1 mEq/kg per hour without appropriate monitoring.

Ongoing Losses: Fluid

Ongoing losses represent the abnormal losses that occur after the one-time determination of a deficit. Examples include continued diarrhea or vomiting, aspirates from a nasogastric tube attached to suction, or the polyuria of an osmotic diuresis. These losses can be measured directly. Other losses, such as abnormal internal collections with an ileus, peritonitis, or edema and external radiant losses, are more difficult to estimate and require experience and careful monitoring of the patient.

Ongoing Losses: Electrolytes

Tables are available to estimate the composition of ongoing losses according to the source of the loss. As a rule of thumb, gastrointestinal losses can be replaced with half-normal saline, transudates reflect the composition of the intravascular space and have the higher sodium con-

Table 5. Two Methods of Rehydration*

	Combined Deficit/ Maintenance	Sequential Deficit/ Maintenance
First 8 hours after bolus	1/2 remaining deficit + 1/3 daily maintenance = 367 mL	Remaining deficit: 400 mL
Next 16 hours	1/2 remaining deficit + 2/3 daily maintenance = 533 mL	Daily maintenance: 500 mL
Total	900 mL	900 mL
*A 5-kg infant who has moderate dehydration (10%, 500 mL deficit) following a 20 mL/kg bolus (100 mL). Remaining deficit is 400 mL; maintenance is 500 mL/d.		

centration of normal saline or Ringer lactate, and radiant losses are sodium-free.

Parenteral Rehydration Without a Calculator of a Moderately Dehydrated Infant

An initial bolus of 20 mL/kg is provided to restore normal hemodynamics; adequacy of the bolus can be assessed by resolution of hypovolemia-induced tachycardia. After the bolus, there are options. A common approach is to provide 50% of the remainder of the deficit in the next 8 hours along with 8 hours worth of maintenance fluid; the remainder of the deficit is administered in the subsequent 16 hours, along with the usual hourly maintenance requirement. Such calculations “work,” but they are unnecessarily complex and may be so daunting as to discourage any calculations, particularly in the middle of the night.

An easier alternative is to recognize that the bolus of 20 mL/kg represents 2% of body weight. If the initial deficit was estimated to be 10%, the remainder after the bolus is 8%. This can be replaced conveniently over 8 hours at an hourly rate of 10 mL/kg (1% body weight per hour), a number that is easy to calculate mentally. The day’s worth of maintenance fluid then is provided in 16 hours. Administering 24 hours worth in 16 hours requires a rate of 1.5 times the usual hourly maintenance rate ($24 \div 16 = 1.5$). By this method, calculations are simplified, and the amount of fluid administered hourly is close to the same as the more complex way, with slightly more at an early point (Table 5). As noted previously, rapid “recruitment” is desirable and often obviates the need to provide the parenteral infusion longer than overnight.

The bolus is normal saline or Ringer lactate; the remainder of the deficit is provided as D₅0.45NS + 20 mEq/L K⁺, and the maintenance fluid is D₅0.2NS + 20 mEq/L K⁺. In summary, the rehydration plan is for 20 mL/kg of normal saline for hour 1, 10 mL/kg of D₅0.45NS + 20 mEq/L K⁺ for hours 2 to 9, 1.5 times

Table 6. Signs and Tests to Monitor State of Hydration

Sign or Test	Problem
1. Physical signs of dehydration on physical examination	May be deceiving if $[Na^+]$ is abnormal; may be influenced by fever (especially pulse)
2. Body weight	Can be fooled by "third spacing"
3. Urine volume	Output also low in syndrome of inappropriate secretion of antidiuretic hormone (SIADH), renal failure
4. Urine specific gravity (SG)	Concentrating ability of infant kidney limited; SG also high in SIADH, renal failure; SG low in pyelonephritis
5. Input and output, with direct measure of all losses	Must estimate maintenance; cannot measure "third space" loss
6. Urea nitrogen (BUN)	Glomerular filtration rate severely reduced before BUN rises; elevated by blood in gastrointestinal tract; infant measure normally lower than adult measure; may mean renal disease
7. Hematocrit	Useful serially but not as single value and not if patient is bleeding
8. Concurrent serum and urine osmolalities	Good for detecting SIADH problem
9. Serum electrolyte concentrations	By themselves, reveal little about state of hydration

From Roberts K. Fluid and electrolyte disorders in infants and children. In: Beers M, Berkow R, eds. *The Merck Manual of Diagnosis and Therapy*. 17th ed. Whitehouse Station, NJ: Merck & Co; 1999

the usual maintenance amount of $D_50.2NS + 20 \text{ mEq/L } K^+$ for the next 16 hours, and usual maintenance thereafter.

Hypertonic Dehydration

Hypertonic dehydration is an exception to the foregoing approach. In hyperosmolar states, fluid is drawn into the intravascular space from the intracellular space, bolstering the circulation. The rapid administration of fluid, as recommended for isotonic states, can create fluid shifts that result in cerebral edema and intracranial bleeding. Finberg described a rehydration protocol that permits fluid and electrolytes to be administered safely and has been widely accepted. A bolus may or may not be needed because the contribution of the intracellular space may have maintained an effective circulating volume. The calculated deficit fluid and electrolyte needs are added to 2 days (48 h) worth of maintenance fluid and electrolyte requirements; the sum is divided by 48 and administered at a constant hourly rate for 48 hours.

Monitoring the Effectiveness of Parenteral Fluid and Electrolyte Therapy

The best monitoring "tests" are the simple ones that all too frequently are overlooked, such as the resolution of signs of dehydration apparent on physical examination: tachycardia and dry mucous membranes (Table 6). Serial weights provide valuable information, as long as there is no "third-spacing." Measurement of urine volume and specific gravity are also helpful. In situations in which the

blood urea nitrogen concentration is increased, it is comforting to see a return to normal, but generally blood tests have little to offer compared with the bedside "tests" noted previously. In particular, electrolyte concentrations do not reflect the state of hydration.

Summary

When planning to rehydrate a dehydrated child parenterally, it is useful to consider the fluid and electrolyte needs separately for maintenance, deficit, and ongoing losses. For maintenance, both fluids and electrolytes are based on metabolic rate. The composition, therefore, is fixed ($D_50.2NS + 20 \text{ mEq/L } K^+$). Systems, such as the Holliday-Segar formula, relate fluid needs to body weight.

In assessing the extent of dehydration clinically, the rule of 5 to 10 to 15 (mild dehydration=5%, moderate dehydration=10%, severe dehydration=15%) applies only to infants. For adolescents and adults, the rule estimates are 3% to 5% to 7% or 3% to 6% to 9%. Intermediate values should be used for school-age children.

A bolus of fluid that is similar to extracellular fluid (ECF) is administered if signs of hypovolemia are present. The amount generally provided to infants and small children is 20 mL/kg (2% of body weight); the volume for adolescents is 10 mL/kg (1% of body weight). If an infant's degree of dehydration is estimated to be 15%, a single 20-mL/kg bolus will improve circulation but not normalize the hemodynamics. For timely

restoration of cardiovascular sufficiency, one or more additional boluses of 20 mL/kg will be required.

Isotonic dehydration estimated to be 10% of body weight can be corrected by 20 mL/kg per hour of ECF-like fluid followed by 8 hours of D₅0.45NS + 20 mEq/L K⁺ at 10 mL/kg per hour. Maintenance fluids, D₅0.2NS + 20 mEq/L K⁺, subsequently are provided, initially at 1.5 times the usual rate for 16 hours, followed by the usual maintenance rate (although, by then, parenteral therapy may not be needed).

Ongoing losses, if significant, should be measured and replaced. When it is not possible to measure the losses, extra diligence must be applied in patient monitoring.

Monitoring should focus on readily available mea-

asures because they are the most helpful: physical examination (to see if the signs of dehydration have improved), weight, urine volume, and specific gravity.

Suggested Reading

- Finberg L. Hypermnatremic (hypertonic) dehydration in infants. *N Engl J Med.* 1973;289:196–198
- Holliday MA, Segar WE. The maintenance need for water in parenteral fluid therapy. *Pediatrics.* 1957;19:823–832
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- Welt LG. *Clinical Disorders of Hydration and Acid-base Equilibrium.* Boston, Mass: Little, Brown; 1955

PIR Quiz

Quiz also available online at www.pedsinreview.org.

9. A 6-year-old girl is admitted for elective removal of a mesenteric cyst. Physical examination reveals a well-hydrated child whose weight is 23 kg and height is 115 cm. She is afebrile and appears healthy. Which of the following is the *most* appropriate parenteral maintenance fluid and electrolytes regimen for her?
- A. 5% Dextrose with 0.20% saline + 20 mEq/L KCl at 65 mL/h.
 - B. 5% Dextrose with 0.20% saline + 40 mEq/L KCl at 95 mL/h.
 - C. 5% Dextrose with 0.45% saline + 20 mEq/L KCl at 65 mL/h.
 - D. 5% Dextrose with 0.45% saline + 40 mEq/L KCl at 95 mL/h.
 - E. 5% Dextrose with 0.90% saline + 40 mEq/L KCl at 65 mL/h.
10. A 2-year-old child presents with a 24-hour history of 10 to 12 large, watery stools and vomiting. Physical examination reveals sunken eyes, weight of 12.5 kg, temperature of 36.8°C (98.2°F), heart rate of 144 beats/min, respirations of 26 breaths/min, and blood pressure of 78/40 mm Hg. His extremities are cool, and the capillary refill time is 3 seconds. Of the following, the *most* appropriate initial intravenous bolus to be administered over the next hour is:
- A. 125 mL Ringer lactate.
 - B. 250 mL 0.9% saline.
 - C. 250 mL 5% Dextrose.
 - D. 125 mL 5% Dextrose with Ringer lactate.
 - E. 250 mL 5% Dextrose with 0.45% saline.
11. A 6-month-old girl presents with vomiting and loose stools of 3 days' duration. Physical examination reveals an axillary temperature of 37.2°C (99°F), respiratory rate of 32 breaths/min, heart rate of 126 beats/min, and blood pressure of 98/68 mm Hg. The anterior fontanelle and eyes are sunken, the lips and oral mucous membranes are dry, and the skin appears doughy. Results of laboratory studies include: serum sodium, 168 mEq/L (168 mmol/L); potassium, 5.2 mEq/L (5.2 mmol/L); chloride, 136 mEq/mL (136 mmol/L); and bicarbonate, 10 mEq/L (10 mmol/L). A *true* statement about this girl's condition is that:
- A. A 20 mL/kg bolus of 5% dextrose should be administered over 1 h.
 - B. Extracellular fluid is depleted more than intracellular fluid.
 - C. Rehydration should occur over 48 h at a constant rate.
 - D. Total body potassium is increased.
 - E. Total body sodium is increased.

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